10-1968

A Marine Physics Project

D Clark

A Keane

P J. O'Halloran

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BULLETIN No. 19

WOLLONGONG UNIVERSITY COLLEGE
THE UNIVERSITY OF NEW SOUTH WALES

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D. CLARK, A. KEANE, P. J. O'HALLORAN

OCTOBER, 1968

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by

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1. INTRODUCTION

The Department of Mathematics at Wollongong University College has embarked on a programme of research in Marine Physics. Most of the work to date has been a theoretical treatment of seiches in basins with irregular boundaries (Clarke 1968) and with sloping bottoms (Clarke 1968). Recently a study of wind generated currents has been initiated.

To support the theoretical work, the Department acquired a long wave recorder which was installed on the S.A.R. wharf at Jervis Bay Naval College early in 1968.

The specific project with which this bulletin is concerned was brought to our attention by recordings obtained at Jervis Bay during a violent southerly storm in May. The present aim is to give a simple outline of the relevant theory and observations and then to post the unanswered questions which will form the basis of a research project having apparent significance for the safety of shipping in Port Kembla's harbour.

2. SIMPLE THEORY

Long Waves

To achieve mathematical simplicity it is usual to consider a class of waves whose wave length is large compared with the depth of the water. The approximations introduced will be valid for waves with a period of a few seconds up to the waves associated with the daily tides.

Restricting ourselves to waves with periods between a minute and a few hours they are propagated under the influence of gravity. For a particular direction of propagation the wave motion is described by the wave equation

$$\frac{\partial^2 \zeta}{\partial t^2} = c^2 \frac{\partial^2 \zeta}{\partial x^2} \qquad (1)$$

where ζ is the wave height at time t and position x, and c is the wave velocity equal to $\sqrt{gh}$, g being the acc^n due to gravity and h the depth of the water.

In the ocean away from the coast the solution of (1) for a pure wave form travelling in the positive x direction

$$\zeta = A \cos K(x - ct) \qquad (2)$$

where $K = 2\pi/\lambda$, λ being the wave length and A is the amplitude. The period of these waves is $T = \lambda/c = \lambda/\sqrt{gh}$.

Natural Periods of Basins

Wave motion in an enclosed basin is determined by the geometry since now we must solve the wave equation (1) subject to the boundary condition that the waves have antinodes on the shore line. The problem is similar to that of considering standing waves on a violin string and the same terminology of fundamental and harmonics is used.

Keeping to the simple one dimensional treatment we now have to solve equation (1) with the boundary conditions $\frac{\partial \zeta}{\partial x} = 0$ when $x = 0$ and ℓ where ℓ is the length of the basin in the direction of wave propagation. The solution is

$$\zeta = A \cos \frac{n\pi x}{\ell} \cos \frac{n\pi ct}{\ell} \qquad (3)$$

where $n = 1$ gives the fundamental mode of oscillation and $n = 2, 3 \ldots$ gives the higher harmonics.

The mode most readily excited is the fundamental since it has less energy than the higher modes. For the fundamental the period is given by $T = 2\ell/c$ and this is called the natural period.

Natural oscillations in an enclosed or partially enclosed basin are called seiches.

<u>Period of Natural Oscillations in Jervis Bay</u>

The mean depth of Jervis Bay is approximately 9 fathoms and its length is 8 miles. Converting to metres $h = 17$, $\ell = 13{,}000$, so that

$$T = \frac{2\ell}{\sqrt{gh}} = \frac{26 \times 10^3}{\sqrt{170}} = 2 \times 10^3 \text{ secs.}$$

$$= 33 \text{ minutes.}$$

This period is observed as can be seen in a day's record of long waves in Jervis Bay. (Fig. 1)

<u>Period of Natural Oscillations in Port Kembla Harbour</u>

For the harbour at Port Kembla the depth of water is $h = 12$ metres, the length of the harbour is $\ell = 1600$ metres and the breadth of the harbour is $b = 1000$ metres. These figures give a period

$$T = 3.6 \text{ minutes.}$$

The complicated shape of the harbour raises doubts as to the applicability of one dimensional theory. An experimental study carried out by the Public Works Department has given a natural period of this order of magnitude.

3. MEASUREMENT OF LONG WAVES

An instrument to measure the amplitude and period of long waves consists essentially of a "pressure pot" and a recording device. The "pressure pot" is installed at a fixed point under water and has a diaphragm which is activated by the pressure of water above it. Changes in pressure (water height) are transmitted through a long column of air via capillary tubing and activate a pen attached to a sensing bellow which marks a chart scaled to give the height of water above the diaphragm.

In order to eliminate short period waves such as surf and the wash of a ship it is possible to include a damping device between the diaphragm and the pen so that only pressure changes, maintained for a desired period, (perhaps a half minute or more) will activate the pen.

A twenty four hour record will show the tidal variation with shorter period oscillations superimposed. A normal record from Jervis Bay reproduced in Fig. 1 shows the two high and two low tides with the natural fundamental long wave of 35 minute period superimposed.

The usual record consists of the combined effect of a variety of oscillations and requires a Fourier analysis in order to separate the various amplitudes and periods of the constituents. When a small number of oscillations dominate the record it is easy to determine the gross features without detailed mathematical analysis.

4. OBSERVATIONS ON MAY 15TH

On May 15th a violent southerly storm hit the coast. Our recorder on the S.A.R. wharf at Jervis Bay recorded the presence of a long wave of amplitude one foot and period three minutes. The day's record can be seen in Fig. 2.

On the same day it was observed that the water in the harbour at Port Kembla oscillated violently and ships had to leave their moorings and stand out to sea.

Long waves of three minute period are common in the ocean (Deacon 1956) and have been studied by Munk (1950) and Tucker (1950). Compared with the natural period of 35 minutes in Jervis Bay it seems that these waves would be too high an harmonic to be generated within the Bay but that they entered from the ocean.

If we assume that the three minute waves recorded at Jervis Bay were also present in the ocean off Port Kembla then we could expect that their entry into the harbour would cause resonance of the natural fundamental oscillation which has a period near three minutes. This assumption is highly significant and needs verification.

The danger to a moored ship in an oscillating harbour is not due to the up and down motion of the water, which is only a foot or two, but to the horizontal motion called ranging. For a three minute oscillation the water could move horizontally through distances of about 20 feet imposing severe strains on the moorings.

Any deductions implied in this section are intuitive and could be wildly inaccurate. The next section outlines a programme of research designed to obtain information which will clarify our present knowledge.

5. RESEARCH PLANS

A number of questions arise from the observations of the last section.

(a) Did the 3 minute waves in Jervis Bay come from the ocean and what was their amplitude outside?

(b) Were waves of the same period in the ocean off Port Kembla?

(c) Were the rough conditions in the harbour at Port Kembla due to excitation by long waves of 3 minute period?

(d) How and when are waves of 3 minute period generated off the New South Wales coast?

Of course some of these questions assume the likely answer to a previous question and if our intuition proves wrong an entirely new set of questions will have to be posed.

To answer the first three questions the main need is for recorders to be placed off the coast at Jervis Bay and Port Kembla, and another in Port Kembla harbour. The public Works Department has supplied us with details of model studies for the harbour and has provided a recording instrument which is being serviced in the College workshop before installation in the harbour. The college has ordered two more instruments with strip recorders so that they will require only weekly instead of daily inspection. It is hoped to position these on secluded islands off the coast.

The last question concerning the generations of waves will require a careful assesment of meteorological observations. Partly for this purpose the College is in the process of setting up a meteorological station. The correlation of weather conditions with the appearance of three minute waves should pave the way for a mathematical treatment of the problem, using a reasonable approximation for the features of the ocean in the immediate vicinity of the coast.

The simple theory in section 2 shows that on assuming 100 fathoms for the average depth of the ocean off the New South Wales coast, the three minute waves have a wavelength of about 5 miles. To consider waves of such length there will be no need to take account of small irregularities which should make the task reasonable.

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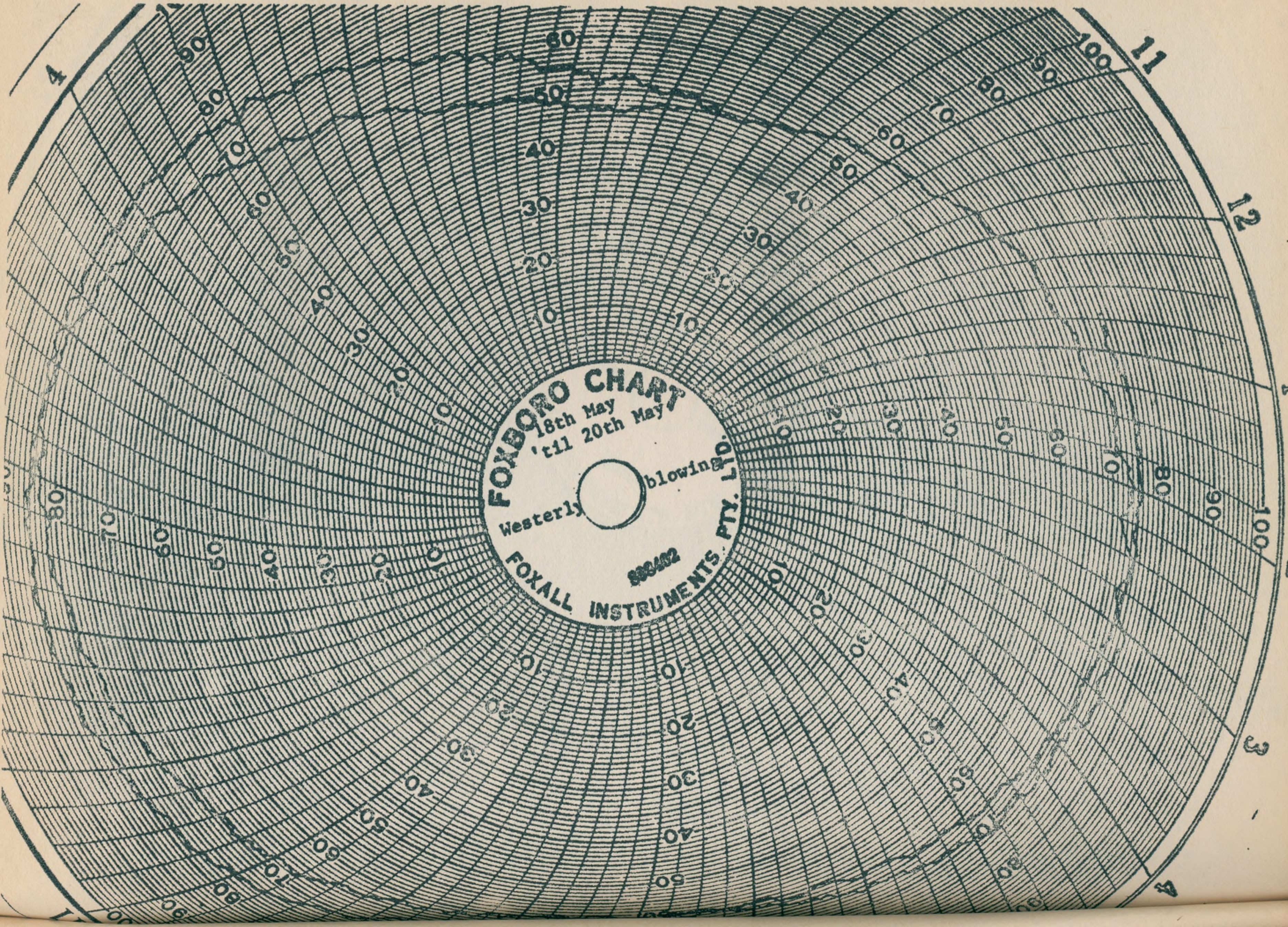
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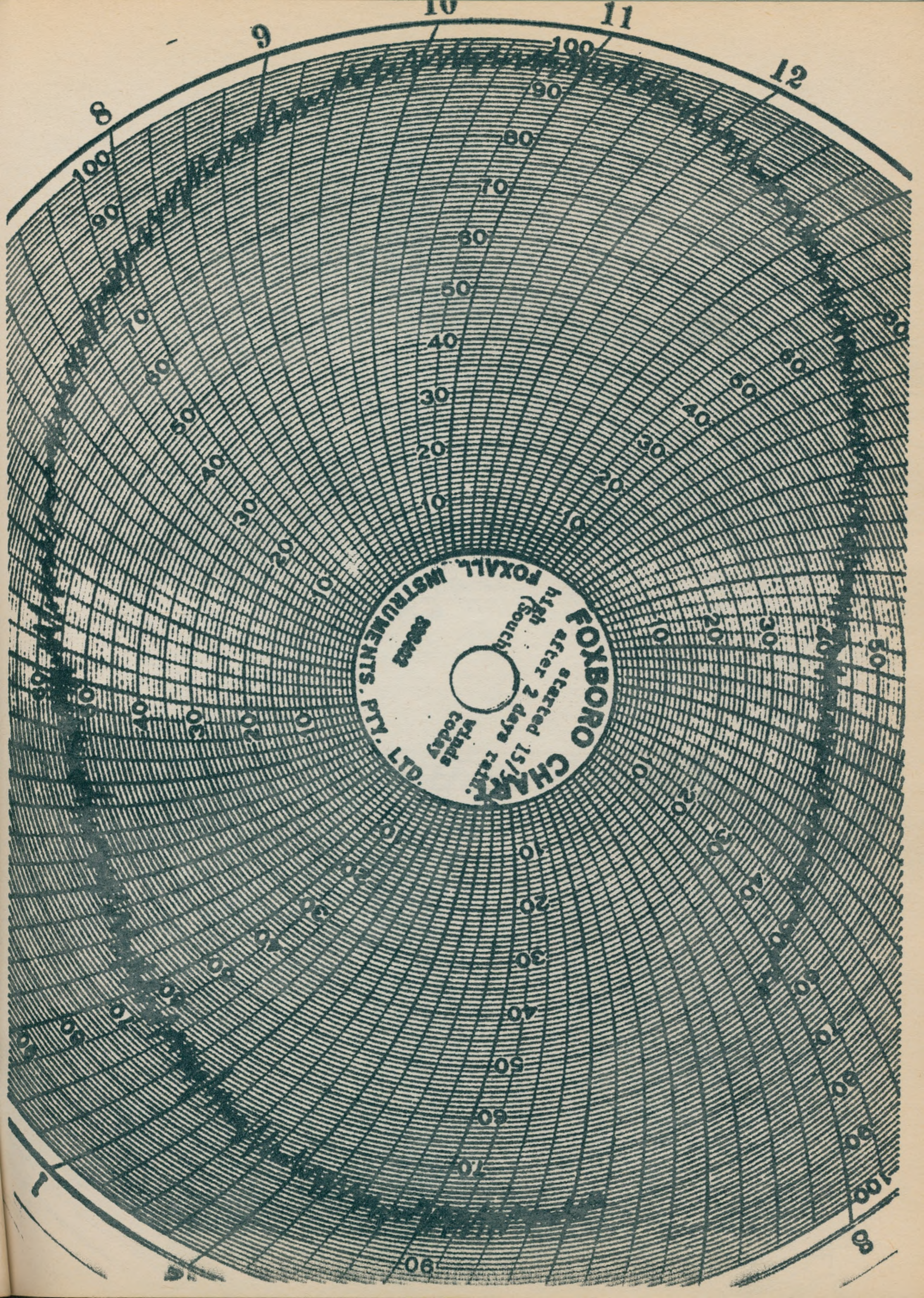
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